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Renewable energy education: A global status review

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ABSTRACT

Need for renewable energy education and training at all levels is globally recognized. During the last three decades a large number of countries across the globe have initiated academic programmes on renewable energy technologies and related aspects. A review of published literature on renewable energy education initiatives across the globe, challenges faced, and potential approaches towards efficient and effective solutions are presented in the paper.

Contents

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1. Introduction

Design, development and dissemination of appropriate renewable energy technologies is important for meeting the growing energy requirement for economic growth as well as for improvement in the quality of human life [1–3]. Development and large scale dissemination of renewable energy technologies has been prioritized by a large number of countries across the globe to provide environmentally sustainable energy supply options to meet their energy demand. From a modest beginning in mid-1970s, considerable progress has been made in several technologies that include wind power, solar photovoltaic and thermal applications, as well as production of biogas, bio-ethanol and bio-diesel from biomass feed stocks [4–8]. However, the overall contribution of non-hydro renewable energy technologies is still very limited as compared to their potential and there is an urgent need to design, develop and disseminate these technologies with minimum dependence on external sources [9–24].

A variety of technological, economic, socio-cultural, institutional barriers are attributed to the poor dissemination of renewable energy technologies. For example some of the technologies developed to harness new and renewable source of energy do not satisfy the perceived needs of the end users while some of these are not yet cost effective [25–27]. Thus, large scale harnessing of new and renewable sources of energy to make significant contributions to the global energy needs would still involve tremendous technological efforts. Development and dissemination of appropriate renewable energy technologies would thus require an adequate number of well trained and competent personnel in all countries of the world [28–38]. Similarly, a majority of socio-cultural and institutional barriers to the dissemination of renewable energy technologies may be overcome, to a large extent, if the potential end users, policy makers and other stake holders are made ‘energy conscious’ by providing them all the relevant information about various issues involved and also about the remedial measures. In fact, the attitudes and preferences of the common public as well as of the decision makers have to be changed for wider acceptance of renewable energy technologies. Education and training in the area of energy in general, and new and renewable sources of energy in particular, is therefore, of prime importance [39–48].

Unavailability of human resource with required knowledge and skills is often identified as one of the key reasons for poor dissemination of renewable energy technologies [28–30]. For a balanced and accelerated diffusion of various renewable energy technologies adequate number of competent and well trained professional are needed (for resource assessment, technology development, system design, installation, operation, repair and maintenance, performance monitoring, information processing, planning, etc.). Workforce development is one of the critical factors to success in implementing any strategy towards renewable energy technology development and dissemination. It is necessary to periodically seek inputs from the industry about (a) any gap(s) between existing and desired levels of renewable energy education and training (b) important courses for professional already employed in the field of renewable energy and (c) required skills and knowledge with the new entrants to renewable energy industry. This necessitates that sincere efforts be made in the area of renewable energy education and training to provide the required technical manpower at all levels [49–61].

As mentioned earlier, the need and relevance of ensuring renewable energy education at all levels is globally recognized. During the last three decades a large number of countries across the globe have initiated renewable energy education programmes. Most of these initiatives pertain to floating of independent graduate level teaching/training programmes or of elective courses in conventional engineering/applied science curricula. Some efforts have also been made to introduce energy-related aspects in the school and undergraduate level curricula as well. While some countries started offering programmes for renewable energy education immediately after the oil crisis of 1970s a large number of countries have started academic programmes in the field of renewable energy as the global climate changes concerns in late 1990s necessitated development and dissemination of renewable energy technologies [62–99].

Many of the efforts made in the past towards the establishment of education and training programmes in the field of renewable energy and other relevant disciplines have been reported in the literature [100–120].

An attempt to present a review of available published literature on different facets of renewable energy education and training is made in this paper with a brief description of the objectives of the renewable energy education; its desirable features, modes and levels; and a review of efforts so far made towards imparting renewable energy education at university level, in schools, for training mechanics and technicians, for policy makers as well as for common public have been presented. Some relevant aspects pertaining to laboratory component as well as the teaching learning resource material for renewable energy education are also presented in the paper. Finally a review of different challenges is followed by conclusions and recommendations.

2. Objectives of renewable energy education

Education is one of the most effective means for providing solutions to the problems faced by the society. Renewable energy education, in essence, is the treatment of various topics and issues related to renewable energy resources and technologies as an independent subject. The broad objectives of renewable energy education pertain to providing functional knowledge and understanding of facts, concepts, principles and technologies for harnessing of renewable sources of energy. Therefore, depending upon its level, the role of a renewable energy education programme should be educative, informative, investigative and imaginative. Renewable energy education and more broadly the energy education has to have the entire population as its target audience. The specific objective(s) of a renewable energy education programme may include [33,34,42,45,46,48,53]

i. To develop awareness among students about the nature and causes of energy related challenges being faced by humankind (such as increasing scarcity and prices of fossil fuels, climate change concerns etc.).
ii. To make the students aware of various types of nonrenewable and renewable sources of energy, their resource potential, existing technologies to harness them, economics and energetics of these technologies, and socio-cultural, environmental and institutional issues related to their development and utilization.
iii. To motivate and prepare the students to make efforts towards development and implementation of alternative strategies to face various challenges faced by energy sector including provision of more energy for satisfying increasing global energy requirement in an environmentally sustainable manner with particular emphasis on efficient and effective harnessing of renewable sources of energy.
iv. To develop functional values and attitudes in the students towards harnessing of renewable energy sources and associated socio-economic and environmental dimension(s).

3. Desirable features of renewable energy education programmes

Desirable features of energy education programmes and relevant issues have also been mentioned in several publications. Renewable energy education programmes should be efficient (able to provide relevant inputs to the target group in minimum time) and economic (maximum number of people educated within available financial resources) besides being effective in achieving the desired objectives. For example, the desirable features of a university level renewable energy education programme may include [121–126]

(a) It should cover all renewable energy resources with particular emphasis (if needed) on some specific ones depending upon the local needs and resource availability characteristics.
(b) It should cover all aspects relevant to the development and dissemination of renewable energy technologies such as (i) resource assessment, (ii) design, manufacture, installation, performance monitoring, trouble shooting and maintenance of technologies, (iii) financial, economic and energetic aspects of renewable energy technology utilization, (iv) socio-cultural acceptability and (v) assessment of associated environmental impacts.
(c) It should establish synergy with energy conservation (wherever applicable) and energy–environment interaction related inputs to the students.
(d) It should provide a balance between theory and practical aspects. Therefore, its curricula should include inputs on laboratory and demonstration experiments, hands-on-skills training, trouble-shooting, design and manufacture inputs besides lectures, tutorials, assignment and seminar, etc.
(e) It should be flexible and dynamic thus allowing for future improvements in the content and structure of teaching/training programme.
(f) It should be compatible with global efforts to facilitate effective and mutually beneficial experience sharing and interaction with other institutions in the world.
(g) To the extent possible, the university level teaching/training programmes on renewable energy education in particular and all other initiatives, in general, must ensure employment/self-employment to the students upon successful completion.
(h) It should preferably be provided in local languages for better acceptance and efficacy (good quality teaching–learning resources materials should also be available in local languages at affordable prices).

4. Modes and levels of renewable energy education

Energy education, in general, and renewable energy education, in particular, will have to be provided at mass level on a global scale. Thus both formal and informal modes of education should be extensively used for this purpose. Formal education includes instructions given in schools, colleges, universities, etc., and is expected to be well planned with purposeful learning experiences based on identified needs and objectives. In this case a long term controlled strategy is used to impart the requisite knowledge and skills to the learner through an organized system of education. On

the other hand, the informal mode of education involves learning from mass communication media and or from organizations which do not impart organized instruction. This mode of education may help (i) those who have never gone to schools, (ii) the unemployed school leavers, and (iii) adults interested in acquiring new skills and knowledge. Informal mode of imparting renewable energy education is likely to be more relevant for developing countries since a large fraction of their children do not receive any formal education. Thus a judicious mix of formal and informal routes of education will have to be used for imparting renewable energy education. Since the adoption of renewable energy technologies requires active participation of common public, it is important to take initiatives that improve public understanding in this regard [127]. A brief write-up on the relevance and potential modalities for enhancing Public Understanding of Renewable Energy (PURE) are presented in Appendix-A.

It is now widely accepted that renewable energy education should be included at various levels in schools, colleges, universities and other academic institutions (Table 1). For providing first hand exposure to the basic concepts and their application, proper efforts will have to be made at the school level. Certificate and diploma level course will have to be introduced for training of personnel for fabrication, installation, operation and maintenance of renewable energy systems. Regular bachelor degree courses in energy engineering in general with specialization in the area of renewable energy and energy conservation may be offered for providing the required manpower for design, development and evaluation of emerging technologies. Finally, for mid-career training of scientists and engineers interested in working on renewable energy technologies or fresh graduates desirous of further specializing in certain specific aspects, suitably framed post-graduate courses may be required. While university level teaching programmes in this field are being initiated across the globe, so far not much has been done in the direction of starting certificate and diploma level courses. Any such initiative would necessitate a thorough study and analysis of priorities and potential of renewable energy education in a comprehensive manner. Several studies have been reported in the literature those aim at assessing the perception of students (and teachers) about renewable energy sources and technologies [128–139].

5. Renewable energy education at school level

The future well being of mankind would also depend upon its ability to make judicious use of presently existing nonrenewable resources of energy (with due appreciation of inter-generational equity in their consumption and utilization) and to harness new and renewable source of energy. Obviously, the problems involved are both immediate and long range. Since many of the viable solutions would be developed in future, one of the most important responsibilities of the present generation of energy educators is to impart suitable education/training at school level to facilitate appreciation of all the energy related complex issues and also to motivate them to seek proper solutions. Concerted efforts should be made to improve the knowledge and appreciation of school students about renewable energy sources and technologies.

Introducing the relevance as well as the issues and challenges in harnessing renewable energy sources at school level is a major challenge. It is at the school level that a permanent liking and preference for renewable energy technologies can be inculcated. Some attempts towards this direction has already been made and reported in the literature [140–153].

While the basic principles of energy conversion and utilization may be introduced in the primary school curriculum, it may be possible to explain the principles of operation of simple energy devices at the secondary school level. Availability of appropriate teaching–learning resource materials is an essential prerequisite for successfully introducing energy related new concepts in primary and secondary school curriculum. As early as in the year 1978, a lecture laboratory curriculum for teaching of alternate and renewable sources of energy within the secondary school industrial arts laboratory was developed at the Montclair State College in New Jersey, USA [147]. The course aimed at providing the students an insight into the identification of specific energy sources and their potential.

Several other groups around the globe have developed school curricula and packages. For example, Victorian Solar Energy Council in Australia started a renewable energy education programme in schools and the primary and secondary school teaching packages were developed for this purpose [154]. The packages were released to primary schools in Victoria at nominal costs in

Table 1
Potential levels of renewable energy education.

Age Group (Years)	Institution	Modalities/type of programme
5–10	Primary school	Introducing simple concepts within the subject of environmental studies and/or any other relevant subject
10–13	Junior high school	Introduction of relevant concepts and demonstration experiments in the science curriculum
13–16	High school/secondary school	(a) Introduction of relevant concepts, demonstration experiments in the science and biology curricula. (b) Introduction of pre-vocational course(s) in the area of renewable energy technologies
15–18	Senior secondary school	(a) Introduction of relevant concepts, technologies, demonstration and laboratory experiments in the Physics, Chemistry and Biology curricula (b) Introduction of vocational course(s) in the area of renewable energy technologies
> 17	Technical Colleges, Polytechnics, Engineering Colleges Institutes of Technology	(a) Certificate and diploma level programmes for technicians and mechanics (b) Undergraduate and postgraduate degree level programmes (c) Short term/on-the-job training courses for updating knowledge and skills
> 25	Any appropriate organization	Mid-career courses, retraining and updating for technicians, installers and also for other professionals
Any age	Any appropriate organization	Awareness and sensitization programmes for national, regional and local government officers, policy makers, administrators and also of general public

1987 and in-service training courses were organized for teachers involved with the use of the packages. The material included in the packages provides for games and activities for experimental work and for the construction of simple experimental apparatus for classroom and outdoor use. Similarly, a new course for secondary and educational solar laboratories was initiated at the Moscow Institute of New Technologies in Education [150]. It was being increasingly realized that the school students should develop an insight into the challenges of engineering designs of energy systems and should be able to follow such a design project through manufacture to testing and performance evaluation. With this objective, in 1990, secondary school students in Victoria (Australia) were invited to design, build, and enter model solar cars in a competition against each other [155]. Considerable amount of work in the area of energy education at school level has also been undertaken at Florida Solar Energy Centre, USA [156].

Attempts to develop solar energy experiments that may be considered for offering to school level students have also been reported [157,158]. The experiments developed were of varying difficulty and covered different important aspects of solar energy utilization. The experimental modules were made from commonly available inexpensive materials.

Interest in harnessing renewable energy sources using appropriate technologies can be inculcated at school level by demonstrating direct relevance of renewable energy utilization for human beings and their environment. Simple laboratory scale demonstration models can be used for this purpose [159]. This approach also helps remove the doubts about causes and consequences of any challenges (such as climate change by the greenhouse effect) faced by humanity. Proper awareness generation initiatives at school level have been found to be very effective in changing the behaviour of the students as well as their parents [59]. It is important to introduce basics of renewable energy resources and technologies in the science curricula of schools. Providing opportunities for hands-on experience and problem-based learning is also recommended at school level. Few initiatives in this direction have also been reported in the literature [145,159–164].

6. Renewable energy education at university level

Efforts to offer university level programmes in the area of new and renewable energy sources have been initiated in many countries. Postgraduate level teaching/training programmes have, so far, been prioritized as compared to full-fledged undergraduate level programmes in this area. A large number of postgraduate level teaching/training programmes that focus on renewable energy resources and technologies have been offered in the past and majority of them continue to be offered [123–125,165–200]. It is widely appreciated that development of structured curricula for university level courses in the area of new and renewable sources of energy is crucial for their successful and effective implementation. In some institutions the educational initiatives on renewable energy are essentially driven by a strong research focus on a specific area, application or one or more of specific renewable energy technologies [201–218]. Some of the important features of existing academic programmes and important issues pertaining to renewable energy education at university level are briefly presented in the following paragraphs:

6.1. Level of education and degree(s) awarded

Both undergraduate and postgraduate teaching/training programmes are being offered at the university level. Though full-fledged postgraduate level programmes still outnumber the undergraduate programmes, a large number of elective courses on renewable energy related topics are also offered under the curricula of undergraduate science and engineering programmes. Interestingly, even at bachelor level, a variety of interdisciplinary programmes (such as Bachelors of Arts programme in Business Administration with focus on Renewable Energy, Bachelor of Science programmes on Energy and Environment Policy, Bachelor of Science programme in Sustainable Energy Management, Bachelor of Applied Science programme in Energy Management, and Bachelor of Science programme in Climate Change and Energy Management, etc.). Some institutions are offering Master of Business Administration (MBA) programmes in areas such as Energy Management, Carbon Management, Global Energy Management, Sustainable Business, Global Energy Management and Sustainable Development, etc. Separate bachelor level programmes for building services and industry that cover the design and maintenance of environment friendly buildings (such as Energy and Building Services Engineering, Energy Services and Technology, Building Services Engineering with Sustainable Energy, etc.) are also being offered now. Short term refresher or continuing education programmes are also offered on a periodic basis at a large number of institutions around the world. A large number of community colleges and other institutions in United States of America presently offer degrees such as Associate of Applied Science (AAS) or a diploma/certificate on topics related to renewable energy. Similarly, a large number of vocational courses are now available in United Kingdom, Germany, Italy and several other countries in Europe.

6.2. Contact mechanism

Majority of the existing teaching/training programmes still necessitate class room contacts. However, in recent years a large number of initiatives towards offering on-line programmes have also been taken, particularly for offering courses for technicians and mechanics. Many programmes now offer both options (on-campus or online study) to the students to choose from. Online programmes offer the flexibility to study from home and also the freedom to learn at one's own pace (except for classes offered via live video or teleconferencing). Online programmes often make use of pre-recorded lectures or reading materials. To make sure that there is no compromise with the hands-on-training component of the study, the students undertaking online programmes also have to be present for specific classes or internship arrangements. It is worth mentioning that some globally renowned institutions such as Stanford University and Massachusetts Institute of Technology offer online courses in the area of energy. Many more institutions may prefer to adopt this strategy in near future. In spite of several positive features of classroom contact mode of programme delivery, web based education may help achieve quality human resource development objective at much lower costs and well within reasonable time limits to achieve the objectives of economy and efficiency.

6.3. Duration of the programme

The minimum duration of full time postgraduate programmes varies from 1 year to 2 years. The bachelor degree programmes are of 4 years of duration. Usually diploma or certificate courses are of 1 year duration. Some institutions also have the provision of enroling working professionals as students on part time basis with classes being held during early mornings or late evenings. Such part time students take longer to complete the course requirements than the full time students.

6.4. Academic department(s) involved in teaching/training

Energy being an interdisciplinary subject, several different academic departments have taken initiative towards offering teaching/training programmes on renewable energy. These include the departments of mechanical engineering, chemical engineering, electrical engineering, physics, civil engineering, environmental engineering and architecture. In some academic institutions, separate departments on energy also exist that offer teaching/training programmes on renewable energy.

6.5. Scope and coverage

A large number of teaching programmes are now framed exclusively around renewable energy sources and technologies. Master level courses are now being offered on highly specialized subjects also such as (i) 'offshore renewable energy' (ii) 'fuel cells and hydrogen technology' and (iii) 'carbon management'. On the other hand, in some of the programmes the courses on renewable energy are supplemented by courses on energy–environment interaction, energy conservation, sustainable development and appropriate technologies, etc. A substantial number of bachelor and master level courses on renewable (or sustainable) energy management are also being offered now.

6.6. Type of inputs(s) provided

As noted from the available course contents of the curricula of a large number of postgraduate level teaching programmes, the inputs provided to the students can be broadly divided into

(a) basic concepts
(b) detailed models for component/device and performance analysis and evaluation, and
(c) issues related to fabrication/manufacture including materials considerations, system design, testing, standardization, installation, operation and maintenance, techno-economic evaluation, and environmental aspects.

It is practically not feasible for a single teaching programme to cover all the above-mentioned aspects for different types of renewable energy technologies particularly at master level. This explains the current trend of offering master level courses on individual renewable energy sources or even its sub-components.

It is observed that the laboratory (experimental) component of the curricula is apparently not being accorded the importance and priority it deserves in majority of the teaching programmes in renewable energy, particularly, in developing countries. It is a serious limitation of the programmes as mere treatment of theoretical aspects of topic without getting sufficient hands-on-skills experience with the hardware can prompt half-baked immature decisions or set wrong priorities for development and dissemination of renewable energy technologies. Rigorous hand-on-skills training and comprehensive inputs on hardware related aspects of relevant technologies must be provided as a part of any curricula on renewable energy technologies. For most of the renewable energy education programmes, particularly in developing countries, there is an urgent need to develop suitable laboratory, demonstration and do-it-yourself type experiments.

Resource assessment is another important area often neglected in a significant number of teaching/training programmes. Similarly, an adequate treatment of the techno-economics and financing of renewable energy technologies is often not included in many of the existing teaching programmes. With a very large potential of decentralized household level use of renewable energy technologies around the globe, it is also critically important that the socio-cultural issues and aspects of renewable energy technology dissemination are properly dealt with in university level teaching programmes.

6.7. Prerequisites for the courses

Given the interdisciplinary nature of academic programmes in renewable energy and likelihood of students from different academic and professional backgrounds participating in the programmes, defining pre-requisites in terms of prior preparedness for undertaking a course is very important. However, a detailed review of the curricula of a large number of existing programmes indicates that adequate attention is often not being given to ensure that all essential prerequisites for each of the courses are explicitly defined. For example, for a course on solar thermal utilization the students should have the basic knowledge of heat transfer, thermodynamics, optics and calculus. It is also desirable that the student has successfully completed a broad course on various sources of energy (conventional as well as non-conventional) prior to studying any advanced course on a specific renewable energy technology.

6.8. Course curricula and employment aspects

There are a good number of academic programmes available in Europe and North America that aim to prepare manpower to conduct research, optimize designs and provide solutions to the challenges being faced by the renewable energy industry. Also there are institutions in these countries that are training manpower for installation, operation and maintenance of renewable energy technologies. Based on the information provided on the websites of these programmes a reasonably large fraction of the students is able to get a job or pursue further higher studies. However, the situation is not satisfactory in developing countries. Though university level programmes have been initiated, structured modalities of preparing and certifying technicians/mechanics are almost non-existent. Moreover, the employment status of graduates from existing degree programmes in this area is not very encouraging in comparison to other standard conventional disciplines in engineering. At present, particularly in the case of post-graduate level programmes, it is being noticed that renewable energy education programmes are not always able to attract the best talented students thus, to some extent, reflecting their employment potential in developing countries. A potential reason for such a situation is that the knowledge and particularly skills acquired by the students do not meet the requirements of the renewable energy industry. For most of the developing countries with large scale unemployment/under-employment, it is necessary that renewable energy education programmes should be properly framed to provide ample job opportunities, besides making the students capable of self-employment.

Prior to the development and implementation of curricula for renewable energy education at university level it is necessary to identify and analyse the potential job opportunities in this field. Depending on the requirement(s) of each type of skilled manpower likely to be required in the field, necessary inputs are provided in the respective course curricula. It is therefore necessary to undertake an in-depth analysis of the knowledge and skills requirements of each job opportunity envisaged with every teaching/training programme in the field of renewable energy. It is necessary to periodically seek inputs from the industry about (a) any gap(s) between existing and desired levels of renewable energy education and training, (b) important courses for professional already employed in the field of renewable energy and (c) required skills and knowledge with the new entrants to renewable energy industry.

Renewable energy education initiatives must also ensure that trained manpower for large-scale systems is available along with skilled entrepreneurs for design, development, trouble-shooting, and maintenance of renewable energy based decentralized systems. For example, the programmes on training and certification of installers initiated in Europe (PVTRIN, SUNTRAIN) for photovoltaic and solar thermal systems primarily cater to the need of small scale decentralized applications.

6.9. Ensuring synergy with educational efforts in the areas of energy conservation and sustainable development

In any efforts towards imparting renewable energy education at university level it is critically important to ensure its synergy with human resource development efforts in the area of energy conservation and sustainable development. Both energy efficiency measures as well as renewable energy initiatives may essentially help achieve the goal of sustainable development. Thus it is necessary to ensure that the relevant inputs are provided to the students in a holistic manner without the risk of repetition and omission. However, as expected, the course structures of a substantial number of existing university level master degree courses on one or more renewable energy technologies are not able to internalize the issues of energy efficiency and/or energy–environment interaction/sustainable development.

6.10. Special efforts to promote renewable energy education

In the initial phase of imparting renewable energy education special efforts may have to be made to satisfy some of the above-mentioned requirements. Support from the government and industry will go long way in strengthening the infrastructure and facilities for this purpose. Several international and regional organizations have supported renewable energy education. For example, UNESCO prioritized postgraduate training of energy engineering students under its Engineering Education and Training Programme. Preparation of teaching–learning resource materials is one major activity under this programme. The Arab League Education Culture and Scientific Organization (ALECSO) also took some initiatives in the area of renewable energy education. The International Renewable Energy Agency (IRENA) has initiated a programme on renewable energy learning partnerships (IRELP) to enhance awareness and improve accessibility of existing facilities for renewable energy education and also provide assistance in new initiatives in developing countries. Some countries have also taken initiatives in this direction. For example, Government of India has initiated 'National Renewable Energy Fellowships' (www.mnes.nic.in) to motivate students to undertake postgraduate studies in this area.

Some academic institutions took lead in establishing formal academic programmes at post-graduate level in the area of renewable energy and have also continued to offer the same for substantially long periods. The experiences may have special value for those interested in starting new programmes. Some such initiatives with which the authors have had the privilege of closely being associated are presented in Appendices B–F.

7. Renewable energy education for technicians/mechanics

One of the challenges presently being faced by many countries in their pursuit for large scale harnessing of renewable sources of energy is the lack of skilled technical manpower for fabrication, manufacture, installation, operation and maintenance of technologies. For example, it has been observed that, besides high quality hardware, the quality of installation also affects the acceptance of a renewable energy technology. While a motivated takeover can play an active role in dissemination of renewable energy systems, inexperienced installers, with their faulty installations, can discourage potential users. Training of technicians to supervise fabrication, manufacture, installation, etc. of renewable energy technologies and of mechanics to actually work on the shop floor and to provide repair and maintenance back up is, therefore, very necessary for sustained development and dissemination of new energy technologies [219–223].

Presently, in other disciplines, education and training for operators, technicians, supervisors, etc. is usually quite common. Manpower at this level are normally exposed to a broad range of topics during academic programmes of 1–3 years duration with emphasis on imparting a variety of general skills commonly required on the shop floor rather than proficiency in any specific field. Such programmes should, in principle, have competency based curricula that focus on expectations from an employee in the work place and in ensuring the ability to transfer and apply knowledge and skills to new situations and environments covering all aspects of work performance. For example, a competency based renewable energy education curriculum for preparing mechanics and technicians for renewable energy sector could be developed through (a) identifying and enlisting different job opportunities in the renewable energy industry, (b) analysing job responsibilities and requirements for each job opportunity, (c) finding out the requisite knowledge, skills and personality traits required for each job responsibility and tasks to be performed, (d) formulation of objectives on the basis of task analysis, (e) outlining study and examination scheme and developing syllabi, and (f) preparation of curriculum document.

Very few initiatives have been reported towards developing teaching/training programmes to prepare mechanics/technicians to work on the shop floor in renewable energy technology manufacturing industries and also to work on installation, operation and maintenance of renewable energy devices and systems. An interesting exercise carried out for assessing the need for developing and implementing technical and skilled worker training for the solar energy industry was presented in Ref. [224]. By forecasting the future manpower requirements for the solar industry and identifying the tasks that should be performed by technical and skilled workers, guidelines have been provided for developing a curriculum to train these workers. A vocational training programme for designers and installers of photovoltaic (PV) systems was developed by Colorado Mountain College in Glenwood Springs (USA) [225]. Initiatives towards training of installer of photovoltaic pumps [226], homebuilders [227], rural technologies [228] and PV technology in developing countries [229] have also been reported.

For an interdisciplinary subject such as renewable energy the curriculum development exercise is rather complex as a variety of compromises and trade-offs is to be made regarding the topics to be included as well as regarding the depth of their treatment within the stipulated time period. In the case of academic programmes to prepare mechanics and technicians the issue is even more complex as a renewable energy mechanic/technician is also expected to undertake many of the jobs handled by sheet metal worker/fitter/electrician/plumber/welder/carpenter and several other such trades which are themselves offered as separate independent courses. Thus, besides the inputs on renewable energy it may be necessary to include relevant inputs from at least some of the above-mentioned trades. One of the possibilities of accommodating both types of contents is to increase the total duration of the proposed programme and providing renewable energy knowledge and skills as an add on component. Of course it would necessitate a very careful and meticulous selection of inputs for the entire programme. It would also be crucial to ensure continuity and consistency in the judicious mix of inputs from

different relevant trades. A detailed study undertaken in a holistic manner is necessary to resolve several such issues in providing renewable energy education to prepare mechanics/technicians for renewable energy sector.

8. Educating policy makers and common public

Renewable energy education is expected to play an important and effective role in promoting sustainable development and also contribute towards improvement in quality of life of a large section of global population. It is necessary that policy makers are aware of the latest advancements in the field of renewable energy and appreciative of their merits and potential towards providing sustainable energy supply options to meet increasing global energy needs. Similarly, educating common public about energy and climate change related issues and exposing them to the state of the art renewable energy technologies is also of immense importance [67]. Awareness generation among potential users is necessary for enhancing the adoption of a new emerging technology. Public awareness campaigns, demonstration exhibitions, etc. are expected to be of great help in this regard. Some such attempts concerning renewable energy technologies have been made in the past and reported in literature [230–237]. It is also important that both the policy makers as well as the common public appreciate the relevance of having appropriate institutional arrangements for imparting renewable energy education.

There is an urgent need to provide proper training to end users on operation and maintenance aspects of renewable energy technologies [238,239]. Such training is critically important for success of renewable energy promotion initiatives, particularly in rural areas. There is a need for educating and training villagers, particularly women, in the use and management of renewable technologies [239]. Efforts to educate farmers [240–244], specialists [245], small scale manufacturers [246], communities [247] and tribal population [248] mid-career professionals [249] and common public [250] have also been reported in the literature. Use of press [251] and television [252] for providing renewable energy education have also been considered and reported.

9. Curriculum development for renewable energy education

Curriculum for an educational programme essentially refers to a set of guidelines for effective teaching–learning–evaluation to enable the students to achieve relevant instructional objectives. A curriculum document must also internalize different considerations that include (a) target audience of programme, (b) aims and objective of the course, and (c) methods of evaluation to be used. Depending on the level, type and other required characteristics an appropriate curriculum needs to be developed. Moreover, interlinkages of a certain academic programme with other academic programmes on the same or related topic(s) at lower as well as higher levels should also be properly understood and taken into account while developing the curriculum.

Development of programme structure and detailed contents of each course included in the structure of an academic programme in the field of renewable energy are critically important components of renewable energy education initiatives. Several efforts towards development of programme structures and course contents are reported in the literature [253–255].

It is essential to prepare a detailed curriculum document and not merely the outlines (syllabi) of the courses to be included in any academic programme on renewable energy as the course outline is usually not sufficient to unambiguously specify the required knowledge and skills to be imparted to the students. Such a curriculum document should provide information about the knowledge and/or skills to be imparted under each lecture of a course (and thus the learning outcome of each lecture) to make sure that the implementation of renewable energy education programmes are independent of the expertise as well as personal preferences and biases of the teachers and/or of academic institutions involved. Preparation of such a curriculum document would necessitate participation of adequate number of experienced teachers of each of the courses included in the academic programme. A detailed curriculum document can also be effectively used in preparation of suitable teaching–learning resource materials for the proposed courses.

While developing renewable energy education programmes (at all levels and particularly in case of programmes aiming to prepare mechanics and technicians) the expected competencies from the students upon successful completion must be kept in mind. For example, the expected knowledge and skills of a mechanic expected to be involved in installation and upkeep of solar water heating systems, solar cookers, solar dryers, solar distillation units, greenhouses, industrial process heating systems and other low and intermediate temperature solar thermal applications should first be listed in a comprehensive manner and then accordingly the contents of the course to be offered be decided. Similarly for concentrating solar power or photovoltaic power generation, all relevant competencies should be identified and the corresponding course contents included.

In the early 1980s, an overview of the training programme in the area of solar energy with particular emphasis on the curriculum development aspects was prepared with particular emphasis on the curriculum development aspects with support from UNESCO [48]. Owing to a somewhat diminished interest during mid-80s the curriculum development in the area of new and renewable sources of energy was not given adequate consideration. In the view of the renewed emphasis being given to the renewable energy education in recent years it is expected that structured curricula will be developed for all levels of education.

So far, primary focus has been on the university level academic programmes though a few initiatives on introducing renewable energy into school level curricula have also been reported. For school level it has been suggested that, to begin with, the renewable energy concepts may be introduced into the various classes as part of the existing science curricula without any significant alteration in existing overall teaching–learning evaluation strategies. At college level an independent undergraduate subject dealing with renewable energy technologies can be offered. Special curriculum documents will have to be prepared for the courses at bachelor and postgraduate level and also for those at the preparation of the courses intended for training of mechanics and technicians. Energy being an all-pervading concept in the context of science and technology, renewable energy education has to be inter-disciplinary and applied in nature and the curriculum must internalize the essence. In fact, while preparing the curriculum for a certain course, the curriculum developers should follow suitable guidelines to adequately limit its contents and scope.

10. Teaching learning resource materials

Availability of appropriate teaching–learning resource materials is crucial for the success of renewable energy education programmes [256]. Since the processes of both teaching and learning are critically affected by the unavailability of appropriate teaching–learning resource materials, in an emerging field such as renewable energy, success of any initiative towards imparting renewable energy education would be strongly influenced by the availability and quality of teaching–learning resource materials.

For example, due to the availability of the book entitled "Solar Energy Thermal Processes" by Duffie and Beckman as early as in the year 1974 and its subsequent revisions [257–260], courses predominantly dealing with solar thermal utilization are still the most commonly offered university level courses in the field of renewable energy. On the other hand, in the absence of standard textbooks, the scope and contents of a course essentially depend upon the expertise, interest(s) and biases of the course teacher.

A variety of teaching-learning resource materials can be used for facilitating an effective interaction between the teacher and the learner(s). These include text books, laboratory manuals, activity sheets/booklets/leaflets demonstration equipment, posters, slides, overhead transparencies, softwares, videotapes, web based tutorials, cassettes, CD's and other audio–visual teaching–learning aids. Teaching/learning aids, self-evaluation packages, etc. may also be developed by making use of modern techniques of communication and information processing. For the purpose of classroom discussion, suitable case studies on relevant aspects can also be prepared.

Preparation of appropriate educational materials for renewable energy education has not yet received the importance and attention it deserves. Good quality text books are not available even for postgraduate level teaching/training in the area of renewable energy that has apparently received maximum attention. Appropriate teaching–learning resource materials need to be developed for academic programmes from school level to university level.

Though a large number of books have already been published on some renewable energy technologies and related aspects the usefulness of most of these books as standard text books for courses offered under academic programmes on renewable energy is somewhat limited. For developing countries the problem is further aggravated by the fact that most of the good quality books being published in developed countries, their availability at reasonable prices is seldom possible. Therefore, preparation of suitable, relatively inexpensive, textbooks, laboratory manuals, teaching/learning guides, etc. in the area of new and renewable sources of energy for all levels of education is very important.

Few initiatives towards development of teaching-learning resource materials for renewable energy education particularly at university level have been reported. For example, development of an integrated package of teaching materials on solar energy and energy efficiency in office buildings through a European collaboration between university and private sector groups is reported in Ref. [249]. To meet the information needs of architects, service engineers, energy managers, etc. 16 modules for mid-career training are included in the package.

Efforts have also been made towards developing specialized instructional kits and software [261–288] and use of installed devices and systems as teaching aids [289–292]. Construction and operation of scaled-down renewable energy devices for use as teaching aids in secondary schools can sensitize the students about the positive attributes of harnessing renewable energy sources.

A noteworthy initiative towards preparation of a variety of resource materials was taken by UNESCO under its World Solar Programme 1996–2005, under which teaching–learning resource materials (such as textbooks, multimedia products and software for self-training and distance learning) were prepared for stakeholders in both industrialized and developing countries through a networking programme. These packages set goals for energy education including environmental awareness, and ethical responsibility towards society. Student-friendly tutorials to enhance learning have also been included.

Some issues and requirements in the development of teaching–learning resource materials for imparting renewable energy education are briefly described in the following paragraphs.

10.1. *Variety and flexibility*

Renewable energy education and training has to be imparted at several levels. Suitable teaching–learning resource materials should be made available for each level of renewable energy education – from school to university level formal and informal programmes on renewable energy education. One of the options is to prepare separate sets of teaching–learning resource materials for each level of renewable energy education. Alternatively, to the extent possible, the teaching–learning materials may be prepared with inherent flexibility to facilitate their use at different levels of renewable energy education. The possibility of using the same book on solar energy for offering introductory courses to university level students and also to technicians and mechanics may also be assessed. The respective teachers should be able to select appropriate inputs without compromising with the efficiency and effectiveness of the teaching/training programmes. Of course, such a flexibility is relatively more easily possible with electronic audio–visual resource materials where one can have a choice of selecting the text (description) being given along with a figure/photograph, the language spoken and problems to be solved, etc.

10.2. *Periodic revision of teaching–learning resource materials*

The teaching–learning resource materials must be revised at periodic intervals to keep pace with the latest advancements in the emerging field of renewable energy. An efficient functional mechanism for obtaining feedback from all stakeholders on the available teaching–learning resource materials for renewable energy education should be established. The feedback can be taken into account during revision of existing resource material as well as in developing new resource materials.

10.3. *Developing suitable mix of teaching–learning resource materials*

In view of quite diverse characteristics of teaching–learning situations/strategies in different countries/institutions it may be necessary to promote a multi-pronged approach in the development of teaching–learning resource materials for renewable energy education. Printed books/manuals, etc. should be supplemented by web-based course module software as well as audio–visual options. Depending upon the facilities available to the teachers and the learners they will be able to make use of a suitable mix of resource materials to meet their requirement.

10.4. *Motivating authors towards preparation of teaching–learning resources materials*

With relatively very small number of students currently engaged in renewable energy education as compared to conventional science and engineering disciplines, it may not be monetarily rewarding for publishers to be involved in the development of teaching learning resource materials. It may therefore be necessary to support preparation of teaching–learning resource materials on renewable energy to motivate competent authors to contribute to this cause. Preparation of quality teaching–learning resource materials requires commitment and dedication from experienced teachers and the same should be duly compensated and rewarded.

10.5. *Experience sharing and information exchange*

All the stakeholders involved in furthering the cause of renewable energy education would certainly benefit from the availability of efficient mechanisms(s) for experience sharing and information

exchange on the availability usefulness, limitations, etc. of the existing teaching–learning resource materials. Information on printed materials as well as web-based resources should be freely available for further affirmative action and use.

10.6. Low price versions of the teaching–learning resource materials

Renewable energy technologies have a potential to meet a major fraction of the gross energy demand in future. These are expected to be more relevant and useful for decentralized villages and semi-urban areas in developing countries of the world. To facilitate human resource development in developing countries at a scale that would match their requirements, it is necessary that the good quality teaching–learning resource materials are made available at prices affordable by the teachers and students in these countries. It may therefore be necessary to subsidize the production and distribution of the relevant resource materials in the initial phase of the human resource development initiatives in developing countries. Similarly, availability of free-to-download materials would be of great help for both learners and educators. Availability of software such as SAM, RETScreen, HOMER is an example of excellent initiatives in this direction.

10.7. Use of modern techniques of communication and information processing

There is a growing need to make use of modern techniques of communication and information processing in the development of teaching–learning resource materials on renewable energy. Electronic communication techniques facilitate (i) very high storage capacity in small space, (ii) very fast information transmission, (iii) almost instantaneous connectivity of one stakeholder with other stakeholder(s) for experience sharing, information exchange, etc., and (iv) development of stimulation model(s) for better interaction between teacher and the learner in a variety of (otherwise difficult) situations.

A variety of information related to renewable energy is now available on the internet. However, the authenticity of this information may have to be verified prior to its use. Some very useful software and information can now be accessed through the internet – some free of charge and others for a fee. RETScreen and SAM fall in the first category, access to all the Elsevier journals through http://www.sciencedirect.com is of the later type.

Attempts have also been made to use modern communication and electronic technologies for facilitating and strengthening renewable energy education initiatives. These include the use of solar powered videos for training [241]. Use of computers by some institutions to facilitate transfer of relevant knowledge and skills for renewable energy education has also been reported.

With the advances in internet and communication technologies it is now possible to offer renewable energy education at international level through web based courses [123]. Some such attempts have already been reported in the literature with details of challenges faced and remedial steps proposed [278]. Internet based education can overcome several limitations of the lecture-textbook approach of course delivery. These include equity amongst all students in terms of inputs, engagement of all students equitably, better accessibility, more avenues and opportunities of interaction amongst teachers, easier updation of contents as well as teaching–learning resource materials and lower cost of course delivery. Several other initiatives on use of web-based learning environment for renewable energy education have also been reported in the literature in recent years.

11. Laboratory component of renewable energy education programmes

The laboratory component of a renewable energy curriculum should aim to meet the objectives pertaining to cognitive, psychomotor as well as affective domains [293–299]. For example, the laboratory is meant to provide experiences that are conducive to the development of cognitive skills such as understanding underlying principles and concepts, drawing inferences and conclusions, verifying established theoretical relationships, knowing the procedures for undertaking experimental work, etc. relevant for development and dissemination of renewable energy technologies. Psychomotor objectives such as carrying out a range of manipulative skills suitable for the learning of renewable energy as a discipline should also be met by the laboratory component of its curriculum. In addition, the laboratory component should help the students to develop skills in observation, recording as well as analysis and interpretation of experimental results. In addition, a laboratory component should also build human relations and attitude.

Some efforts towards developing laboratory experiments on renewable energy, offering demonstration experiments and other relevant instructional equipment have also been made in the past. The laboratory component of a renewable energy curriculum should take into account the following [300–310]:

(a) It should include experiments related to basic scientific/engineering fundamentals that are of direct relevance to the various renewable energy harnessing technologies and processes. Such experiments would be quite useful in providing exposure to students from diverse academic and/or professional backgrounds of a variety of relevant facets of energy conversion and/or utilization.
(b) The student should be able to interpret the results of the experimental investigations carried out in the laboratory component to derive useful inferences for assessment of technological, economic, ecological and environmental implications of various energy conversion, transport/transmission and utilization processes in general, and renewable energy technologies in particular. Thus the experimental investigations included in the laboratory component should have a common link (energy) with direct relevance to one or more of the practical aspects of energy conversion, transmission, distribution and utilization.
(c) In view of an increasing energy consciousness of both the energy producers as well as consumers, it is expected that the laboratory component of a teaching programme in renewable energy is flexible enough to allow inclusion of experiments dealing with the latest trends in this area. Inclusion of experiments on potential renewable energy technologies for future may be quite rewarding for students.
(d) In addition to the controlled laboratory experiments generally offered to the students which do not allow any deviation from a pre-specified procedure, to the extent possible, there should be some experiments allowing the students in the choice of procedure and methods of evaluation during the course of experimental investigations. Energy being very closely associated with everyday life, encouraging students to experiment with their ideas about efficient and economic harnessing of renewable sources of energy could promote innovation and entrepreneurship.

One of the major constraints in the successful establishment as well as regular operation and maintenance of renewable energy laboratories is their large requirement of space and funds for their establishment as well as recurring financial assistance to maintain

and operate functional laboratories. Another issue is limited number of contact hours available for the laboratory component. Thus, often it may be desirable to revise the programme duration and/or distribution of theory and laboratory hours within a specific duration prior to the implementation of a programme on renewable energy education, particularly at university level.

12. Issues and challenges in renewable energy education

Renewable energy education is a relatively recent initiative. The academic programmes currently being offered on renewable energy vary considerably in the types of renewable energy resources included in the curricula as well as in the extent of their coverage. Moreover the relative share of laboratory component, field visits, etc. also varies amongst various academic programmes. Being an interdisciplinary and end-user driven field (except large-scale grid connected power generation), a variety of issues must be properly addressed to make the educational efforts efficient and effective. Besides acquisition of knowledge and skills a renewable energy professional should be creative and imaginative to be able to develop appropriate solutions for specific situations. This being a new and emerging area, the associated professionals should also be aware of their responsibility and should be able to communicate and organize green solutions wherever feasible. Some important issues are briefly described in the following paragraphs [311–316]:

12.1. Need to ensure synergy between energy and environmental education

In the prevailing scenario of increasing environmental consciousness, it is very likely that all potential energy solutions will be rather strictly guided by their short- and long-term effects on environment and sustainable development considerations. It is crucial for all the energy resource–technology combinations (envisaged to be used for meeting the present as well as future energy requirements of the global society) to be environmentally sustainable. Therefore adequate inputs regarding the ecological and environmental implications of different energy resource–technology combinations must be provided as a part of renewable energy education to ensure that sustainable energy paths are developed and implemented with due cognizance of the potential role of renewable energy technology in the same. Conversely, efforts towards imparting environmental education must ensure that adequate inputs are provided to the students so that they are able to undertake in-depth assessment and evaluation of various potential energy supply options to meet the increasing global energy demand. Moreover, the student should be able to suggest remedial measures wherever required to minimize the adverse environmental impacts of the energy solutions opted by the end-users. It is, therefore, necessary that inputs for both energy and environmental education are provided in a synergetic manner. Extraction, conversion, and utilization of conventional (fossil fuel) energy sources being the primary causes of environmental degradation, it is critically important that both energy and environmental planning strategies and initiatives are made in cohesion. It is also important to ensure synergy between initiatives towards human resource development in renewable energy sector and the manpower requirements for energy efficiency and energy conservation activities as both contribute towards the goal of sustainable development. Thus it is necessary to ensure that relevant inputs are provided to the students in a holistic manner without any repletion or omission of inputs.

12.2. Continuity and consistency in renewable energy education

Another dimension of energy education, in general, and renewable energy education, in particular, that merits immediate attention is to ensure continuity and consistency in the inputs given at different levels. Incidentally, immediately after the oil crisis of the early 1970s, more emphasis was given to university level courses with even more prominence to postgraduate level courses. As a result, the inputs provided in these postgraduate courses necessarily included very simple introductory concepts, definitions, etc., as well as advanced inputs. With the realization of the fact that renewable energy education has to be imparted at other levels as well, teaching programmes at lower levels were also initiated in due course. While specialization/elective courses are offered in undergraduate degree programmes, efforts have also been made to introduce relevant concepts at the primary/secondary/senior secondary levels. Initiatives have also been taken towards offering certificate/diploma level courses in these areas for mechanics and technicians and also to introduce these topics in relevant vocational courses. However, for a variety of reasons, the above efforts have been somewhat disjointed and unable to ensure much needed continuity and consistency in the inputs provided in various courses at different levels. For example, there is no conscious effort to ensure that the basic definitions and concepts being introduced at school level are not repeated in the university level courses. There is an urgent need to develop a comprehensive structured framework for providing renewable energy education at different levels and for different target groups in an efficient and effective manner. While maintaining continuity in the inputs gradually provided at various successive levels, efforts should also be made to avoid any repetition. In cognizance of the fact that, students can adopt a variety of routes to acquire higher levels of skills and knowledge (besides degree/diplomas/certificates), it is crucial to ensure that the necessary inputs are provided in a gradual manner in all possible routes of formal and informal education.

12.3. Renewable energy education and employment

In order to ensure that share of renewable sources of energy in the global energy supply mix is substantially increased, large scale dissemination of renewable energy technologies is necessary. This will lead to an increase in the required number of knowledgeable and skilled manpower to design, develop, install, operate, repair, and maintain renewable energy systems [317–326]. An important characteristic of renewable energy technology development and dissemination is its effect at two distinct levels. While the centralized large scale harnessing of renewable energy sources (such as electric power generation using solar, wind, geothermal, waves, tides, ocean thermal gradients, mini-hydro, etc.) and large-scale industrial process heating application would, in general, provide employment opportunities in the organized sector, the decentralized (invariably household-level) applications of these sources (improved cook-stoves, solar cookers, biogas plants, solar photovoltaic lanterns, solar domestic hot water systems, etc.) have immense potential for creating skilled manpower requirements usually centred around private/individual entrepreneurs. To meet the manpower requirement of both the above types of potential renewable energy applications, it is important that educational efforts in this area take into account the job requirement of both types of applications. Renewable energy education must, therefore, ensure that trained manpower for large-scale systems is available along with skilled entrepreneurs for design, development, trouble-shooting, and maintenance of renewable energy based decentralized systems.

Another aspect of renewable energy education that merits immediate attention is its effectiveness for getting a suitable job, particularly at higher levels of education. At present, particularly in the case of post-graduate level programmes, it is being noticed that energy education programmes are not always able to attract the best talented students thus, to some extent, reflecting its employment potential. For most of the developing countries with large scale unemployment/under-employment, it is necessary that renewable energy education programmes should be properly framed to provide ample job opportunities, besides making the students capable of self-employment.

12.4. Approaches for imparting renewable energy education

Human resource development efforts to provide the required manpower for design, fabrication, installation, operation, and maintenance of various renewable energy technologies and systems can be made in several ways. In one of the possible approaches, that were essentially adopted immediately after the first oil crisis of 1973 and are still being followed, scientists and engineers from relevant standard conventional (sometimes called parent) disciplines can diversify into the field of renewable energy by either acquiring additional inputs by self-study or through suitably designed continuing education and training programmes. Alternatively, independent academic programmes for meeting the need of renewable energy engineers specialized energy engineers, scientists, technicians, and mechanics can be specifically trained to meet the associated challenges. Both these approaches have associated merits and limitations and it is necessary to further evaluate and study the implications of each of the routes as long-term strategies for renewable energy education.

12.5. Trade-off between breadth and depth of renewable energy courses

In most renewable energy education programmes, often a trade-off has to be made between the breadth and the depth of each of the courses included in the programme. For example, if a single introductory course (of about 45 contact hours) is expected to provided inputs on all different renewable energy sources such as solar, wind, biomass, hydro, geothermal, waves, tides, ocean thermal, etc., only basic concepts (knowledge and understanding level) could be introduced in the course and detailed treatment (designs, analysis, evaluation, synthesis, etc.) may not be possible. As a consequence, even after successful completion of such a course the students are only aware of different possible technological options for harnessing renewable sources of energy but are not able to acquire competence for their design, fabrication, performance evaluation, etc. This has, in the past, led to a variety of problems since manpower with half-baked knowledge is unable to prepare and implement an effective strategy for large-scale sustainable dissemination of renewable energy systems. In fact, in many cases, their efforts have resulted in distorted prioritization and non-judicious allocation of scare resources and funds.

12.6. Course structure and curricula

During the initial evolutionary stage the course-structures of the renewable energy education programmes often have the subjective bias of the educators/professionals developing and implementing the curriculum. A careful analysis of the course contents of many teaching/training programmes on new and renewable sources of energy reveals that, more often than not, the curricula are strongly driven by the expertise of available teachers rather than the inputs to be given to the students. Such a strategy, though unavoidable at times, may lead to a mismatch between the knowledge and skills required for the jobs to be undertaken by the student (when employed) and those acquired in the programme. As a consequence (i) the students are not provided the desired inputs, and (ii) the areas in which expertise is available are often given undue importance thus possibly introducing unwarranted biases in the minds of the students.

As discussed in Section 11, a proper balance between theoretical and practical inputs is crucial for any renewable energy education programme. The laboratory component of renewable energy education programme must ensure enough hands-on training of the students. There is an urgent need to develop suitable experiments that can be offered at different levels.

12.7. Unavailability of books and other teaching–learning aids resource materials

As discussed in Section 10, unavailability of good quality textbooks and other teaching–learning resource materials at reasonable prices is another important bottleneck in providing proper renewable energy education. It causes considerable problems to students. Moreover, in the absence of standard textbook(s), the coverage of a course predominantly depends upon the expertise and biases of individual teachers.

12.8. Global interaction and cooperation

A close interaction among organizations imparting renewable energy education at national, regional as well as international level is necessary for increased efficiency, economy and effectiveness of these programmes. In cognizance of the need for collaboration in renewable energy education, several such collaborative activities have been undertaken [193]. Rapid growth in renewable energy industry is providing new opportunities of a variety of collaborative activities between industry and academia. Also it necessitates establishment of well equipped functional mechanism for imparting requisite knowledge and skills.

Existence of efficient functional networks for information exchange, facilitating collaboration and mutual experience sharing would go a long way in strengthening renewable energy education initiatives. Establishment of International Association for Solar Energy Education (IASEE) was a very important step in this direction [327–335]. Several national/regional branches of IASEE (Appendix-G) were also established and a variety of collaborative activities such as organization of conferences and workshops, academic exchanges, etc. were taken by these networks. Mutual cooperation amongst various organizations can be of immediate help in standardizing the course curricula, preparation of text books, teaching/learning aids and sharing of experiences with regard to the effectiveness of the programmes in achieving the objectives, etc. Establishment of an active global network in the area of energy education will go a long way towards fulfillments of the objectives of energy education programmes. An interesting collaborative activity in this area is the European Master in Renewable Energy which is a programme offered by a consortium of universities with each university having demonstrated experience in teaching and research excellence in a particular renewable energy technology. The students must study at two of these universities for completion of their degree requirement. A recent initiative (IRELP) towards renewable energy learning partnerships taken by the International Renewable Energy Agency may provide much needed platform for collaborative efforts in renewable energy education.

12.9. Need for competent and committed teachers

The role of teachers in preparing manpower for development and dissemination of renewable energy technologies is very important. It is therefore necessary to motivate and facilitate dedicated and competent professionals to take up renewable energy education as a profession [336]. Regular periodic refresher courses should be also organized for teachers involved in renewable energy education. It is strongly recommended that, to begin with, the science teachers in primary and secondary schools be provided in-service training to be equipped with the requisite inputs.

12.10. Need for special focus on renewable energy education in developing countries

Efforts have also been made to provide renewable energy education and training in some of the developing countries. However, most of these efforts have been made in the area of postgraduate level courses in universities, engineering colleges and institutes of technologies. Introducing relevant inputs into the school curricula has not yet been seriously considered. Similarly the programme for technicians and mechanics are also not available. Sometimes refresher courses are organized. Professionals from majority of the developing countries have usually been going abroad for education and training in this area. Moreover, a variety of problems are yet to be resolved to provide renewable energy education in an efficient and effective manner in developing countries.

Some of the existing characteristics of developing countries that may directly or indirectly affect the development and establishment of renewable energy education programmes include

(a) In order to improve the quality of the life of majority of their population it is imperative for the developing countries to provide more energy per capita to its people.
(b) Most of the developing countries are oil-importing which necessitates developing a suitable infrastructure for harnessing of new and renewable sources of energy as early as possible. In many developing countries, however, the R&D programmes in this area have been initiated very recently.
(c) The developing countries, in general, have good insolation characteristics and moderate to high wind speeds on a large portion of their geographical area. Similarly, most of these also have biomass feed-stocks for use as a renewable resource of energy.
(d) In most of the developing countries, a large fraction of the population still does not receive education through schools/colleges. Hence there is need for informal education programmes in renewable energy.
(e) An acute lack of resources is another common characteristic of most of the developing countries. One of the major constraints in promoting renewable energy education activities on a large scale is the unavailability of funds with the schools, colleges and universities in the developing countries. Being interdisciplinary and predominantly hardware intensive, renewable energy education and training efforts require a considerable amount of funds to provide the bare minimum inputs. In fact, some extent, unavailability of appropriate teaching-learning resource materials in developing countries can also be attributed to lack of adequate funds.
(f) Unemployment/underemployment prevails in almost all developing countries thus making it very necessary that renewable energy education is directly linked with employment opportunities. Thus, unless carefully planned, the manpower with certificates/diplomas/degrees awarded in the field of renewable energy may not get suitable employment. Therefore, prior to the development of any course-curriculum it is necessary to identify and analyse the potential job opportunities in the field of renewable energy. Depending on the job requirements of each type of skilled manpower the necessary inputs to satisfy the cognitive, psychomotor and affective domains of education must be provided. This necessitates an in-depth analysis of the job requirements for each job opportunity (self or wage employment) envisaged with a specific teaching/training programme in the field of renewable energy. Only then the syllabus for the respective courses should be formulated.
(g) At present, in most of the developing countries, there is a serious lack of trained teachers, suitable text books and other teaching–learning resource materials in the area of renewable energy.
(h) The local socio-cultural issues are quite detrimental in the mass level adoption of renewable energy technologies.
(i) In almost all developing countries the problem of energy is generally compounded by other important issues related to health, nutrition, etc. It is therefore necessary that the renewable energy education is suitably linked with other relevant aspects as well.

In view of the above, special efforts need to be made to establish appropriate educational activities in developing countries to enable them to harness renewable sources of energy for the benefit of their population in a holistic manner.

13. Conclusions and recommendations

The existing renewable energy education programmes in general, and university level teaching/training programmes, in particular, are facing a variety of challenges that include (a) unavailability of well structured curricula for imparting renewable energy education at all levels, (b) lack of motivated and competent teachers/trainees at all levels, (c) unavailability of adequate funds for establishment of well equipped laboratories, libraries, etc. and (d) uncertainty on the employment prospects of the student successfully completing these programmes. It is therefore necessary that relevant issues pertaining to all the above challenges are thoroughly understood and efforts are made to resolve the same to facilitate efficient and effective renewable energy education in an economic manner.

The following recommendations may be made for strengthening energy education programmes in general and renewable energy education, in particular, at all levels:

(a) Concepts and courses dealing with renewable energy sources and technologies must be introduced from primary classes through all formal and informal stages of education. All sections of the society should be made aware of existing energy and environment related problems and should be motivated to seek and contribute towards appropriate solutions. It is necessary to ensure consistency and continuity in the inputs provided at different levels to maximize the overall efficiency and effectiveness of the renewable energy education strategy. While the inputs given at certain level must match with the expected job responsibilities it is necessary to maintain a clear distinction between the learning objectives of two different level courses.

(b) There is an urgent need of developing and implementing structured course-curricula for all types of teaching/training programmes on renewable energy. To the extent feasible and implementable, the curricula may be standardized at the

national, regional or even global level to facilitate technology transfer and exchange of know how.

(c) Renewable energy education programmes must offer a mix of academic as well as hands-on-skills training to the students. The latter can be accomplished by conducting laboratory experiments, practical demonstration of operational systems, fields visits and field installation of actual working systems. Wherever applicable, the students may be encouraged to undertake hardware oriented projects during the course of the teaching/training programmes.

(d) Preparation of text books, laboratory manuals, teacher's guides and other teaching–learning resource materials for all levels and modes of educations in the field of renewable energy is very important for successful implementation of teaching/training programmes. Use of modern techniques of communication and information processing as well as of computer aided instruction may further be encouraged without compromising with the need for rigorous practical hands-on exposure to the students. Wherever feasible, novel open and flexible modalities of preparing the required manpower in the field of renewable energy employing inexpensive teaching–learning resource materials (without compromising into the educational standards) may be evolved and implemented.

(e) Sincere efforts must be made to educate all the members of the society at large about the basic concepts of efficient energy utilization and also about the various renewable energy options available to them. Use of mass communication media, organization of exhibitions and trade fairs, etc. and offering community college courses and adult education programmes are some suggested mechanisms for this purpose.

(f) It is necessary to organize short term courses/workshops, etc. for providing basic input about renewable energy and relevant topics to the policy makers and other associated administrative personnel. It is also necessary to establish facilities and device mechanisms for the in-service training of existing teachers to ensure introduction of renewable energy topics at school level and also for ensuring that the knowledge and skills of the teachers are updated on regular periodic basis.

(g) A close interaction among the organization imparting energy education at national, regional as well as international level is quite necessary for increased efficiency, economy and effectiveness of the teaching/training programmes.

(h) The employment aspects of renewable energy education programmes which are offered beyond the secondary/high school level must be realistically analysed before starting the programme. The university level teaching/training programmes should be designed to provide ample job opportunities and/or should be capable of providing self-employment. To attract best student talent to renewable energy education programmes better promotion, stronger links with the industry as well as research community and increased functional collaboration among institutions engaged in this activity are required.

(i) Since the primary goal of any educational programme is to prepare the population for its future, it is critically important to make a careful assessment of renewable energy education and training needs for societal needs in future. Renewable energy education must be taken very seriously, as its present status is far from satisfactory. In fact, any half-hearted effort in this direction would do more harm than good. Concerted efforts must be made to impart renewable energy education in a comprehensive manner. Specific education and training needs in the area of renewable energy must be assessed and the capability of existing institutions engaged in human resource development must be evaluated and accordingly strengthened. Moreover, the objective of teaching/training programmes on renewable energy should be consistent with the development strategy followed by the country/region.

(j) It would be useful to establish guidelines and standards regarding university level academic programmes in the field of renewable energy so that a suitable system of accreditation of renewable energy education can be established and efficiently executed. Similarly, for training to make the desired effect on renewable energy technology development and disseminations appropriate modalities for accreditation of training programmes may also be encouraged.

(k) Suitably framed regulations such as the Environmental Education Act in Taiwan [337] may help promote renewable energy education. However, for any regulation for promoting renewable energy education to be successful, it should involve stakeholders [145] that may include academia, industry, policy makers, potential users, financiers and so on.

(l) It is important to remember that educational programmes in the area of renewable energy are likely to evolve with time at a much faster pace than academic programmes in established disciplines. Consequently renewable energy education programmes would require considerable time to reach a reasonably satisfactory stage through continued improvement in its curriculum structure, integration and assessment depending on technological developments, energy policy changes user feedbacks and other available alternatives for the intended envisaged beneficiaries.

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Appendix-A. Public Understanding of Renewable Energy (PURE)

A.1 Introduction

Public Understanding of Science (PUS) is today an established concept. There is even since 1992 a scientific journal with this name. A 3-fold definition of PUS given in Ref. [338] is (i) “Debunking of superstitions, half-knowledge, complete and utter ignorance, misunderstanding and mumbo-jumbo, and virulent memes that give rise to anti-science.” (ii) PUS is to “improve science literacy, to mobilize favourable attitudes in support of science and new technology, to increase interest in science among young people and other segments of society, and to intensify public's engagement with science in general and for the greater good of society.” (iii) “PUS considers common sense as an asset” and PUS research should “chart out the public controversies arising from new developments and in different regions of the world” exemplified by “the impact of the climate of opinion on knowledge production.”

During the planning of Sweden's first science centre The Futures' Museum, one of the authors (Broman) gave following seven reasons for creating a science centre [339–341]: (i) Give an insight that science is understandable. (ii) Awaken curiosity. (iii) Give people the courage to experiment. (iv) Facilitate public understanding of science. (v) Provide preparedness to withstand superstition and pseudoscience. (vi) Amuse and entertain. (vii) Provide aesthetic experiences.

Underlying the statements is the notion that PUS is important, which scientists happily believe, and we of course agree, but it is

not as simple as that. There are e.g. so many different sciences (which in turn are divided into many disciplines). A rather popular notion is that "science" is that same as "natural sciences", but that is not the case. Science also "includes engineering and medicine, the social sciences and humanities, old and new disciplines with clear boundaries, but also… fuzzy transdisciplinary techno-sciences" [338].

It is also vital to identify target groups, since some may be more important than other. Loosely defined target groups frequently mentioned are young people (in the world of science centres often restricted to the "7-eleven group" of elementary school children), voting adults, and decision makers. Other interesting group may include teenagers, refugees, religious fundamentalists, senior citizens, people living in villages as well as cities, just to name a few.

It is also important to identify groups of science communicators. As an example, The European Science Communication Network ESCOnet, 2005-8 developed and conducted a series of workshops on science communication training aimed at young post-doc researchers [342].

PUS is therefore important for a variety of target groups including common public. A potentially important subset of PUS is Public Understanding of Renewable Energy (PURE) [343]. The main questions in this regard are "is PURE important?" and, if the answer is *yes*, "how could PURE be achieved, and which means of achieving PURE are potentially useful?"

A.2. Importance of Public Understanding of Renewable Energy (PURE)

Four reasons for the importance of public understanding of renewable energy are

(i) The earth is a lonely planet in a vast space, not as crowded as the impression one gets from science fiction movies. For humans to move from a destroyed earth to another hospitable planet is just impossible.
(ii) The earth is a planet alive with a dead sister and a dead brother. Venus is too hot for life due (also) to too much greenhouse gases, while Mars is too cold due (also) to too little greenhouse gases.
(iii) Anthropogenic influence on the world's climate, in particular climate warming due to release of greenhouse gases like carbon dioxide (CO_2) and methane (CH_4) is generally agreed upon among scientists
(iv) One major source of greenhouse gases is combustion of fossil fuels, which has to be replaced by increased energy efficiency and large-scale worldwide dissemination of appropriate technologies for harnessing renewable sources of energy.

A reasonable conclusion is that public understanding of renewable energy is important. An important task of an initiative on PURE would be to identify pros and cons in this respect. There are also several attendant questions: What do professionals – researchers, planetarians, teachers – say? How interested is the public – and different target groups – in renewable energy, and what do they already know? Which disciplines in renewable energy science are more important than others? A very crucial role exists of common people in the success of this objective of large scale harnessing of renewable sources of energy, since as adoption as well as design, developing, manufacturing, etc., would require their participation.

A.3. Approaches and means to achieve PURE

There are of course several different channels that can be and are used in conveying attitudes towards and knowledge of renewable energy subjects: Newspapers, TV programs, books, interactive exhibits in science centres, lessons in the school. Different media certainly attract different target groups. One of the important tasks is to assess the potential role that science centres with interactive exhibits can play in enhancing PURE. It is worth mentioning that all science centres are not identical – there is a great difference between large science centres (like Nehru Science Centre in Bombay, Cité de Science and Technologie in Paris or Exploratorium in San Francisco) and small ones (like Ekohuset in Strömstad and Molekylverkstan in Stenungsund; both Sweden).

It is well established that a combination of watching a planetarium show and doing experiments related to the show is very useful. Traditionally, planetariums used to be devoted basically to astronomy using a classical opto-mechanical star projector. However, today planetariums increasingly concentrate on edutainment shows with astronomic content, using all-dome video technique. Shows related to climate change and its solutions would be easily produced using modern planetarium projectors and would fit nicely under the planetarium dome. Two further opinions on interactivity are listed below:

Michael Spock, former Director of *Boston Children's Museum*, borrowed the Chinese philosopher Confucius' proverb as a motto for the museum: I hear and I forget, I see and I remember, I do and I understand (cited in Ref. [344]).

William Glasser [345] wrote: We learn 10% of what we read, 20% of what we hear, 30% of what we see, 50% of what we both see and hear, 70% of what is discussed with others, 80% of what we experience, and 95% of what we teach.

An important component of achieving PURE is likely to be interactivity and hands-on experience, and useful environments for this are science centres. Some examples of this are shown elsewhere [346] in photographs from the Teknoland outdoor science centre 2000–2001: Yourself a Sundial, Toddlers' Teknoland, Solar Energy Surfaces, The Greenhouse, and The Solar Heated Chess Board.

Educating General Public

Ordinary people are the ultimate users of energy from the sun and accordingly need basic knowledge and understanding to make use of this new technology and be motivated to use it. A number of ways to educate large populations are readily available. Some proven examples include

Mass media: This includes newspapers, weekly magazines, radio, and TV. You address professional journalists, and if you manage to teach them some basic facts, they will frequently make o good job in popularizing what they have learned.

Exhibitions: We have built both Science Centre exhibitions (1986 and 1990 on solar measurements for the Futures' Museum in Borlänge, Sweden) and travelling exhibitions (Alternative Energy 1976, Solar Energy Exhibition 1989; Broman and Gustafsson 1991). The educational value of an exhibition is greatly improved if it provides hands-on experiences.

Another kind of exhibition is the trade fair with commercial and institutional exhibitors. Such fairs can range in size from the 100 m^2 or so of exhibitions that accompany SERC's Solar Energy Days to the multi-acre exhibition of the UN Conference on New and Renewable Energy Sources of Energy in Nairobi 1981. Such fairs contain up-to-date technological information for many categories of visitors and should be made available both to professionals and to the general public.

Popular Lectures, etc.: General admission popular lectures sometimes attract good-size crowds, especially if arranged as debates or panel discussions, or if a well-known speaker is featured. Lectures can also be video-taped, and can, with appropriate solar powered equipment, be shown just about anywhere [242].

Community college courses: These are excellent in giving interested individuals more-than-basic knowledge. The aim of such

courses can even be that every participant builds his own solar collector or any other device.

Other examples of contributing towards PURE include renewable energy education and training in an Egyptian village with a programme consisting of public presentations, group discussions, simple solar kits, children competitions, technical training workshops, exhibits with working models, working systems, video-training systems, and a communal library [242] and organization of a regional training workshop in Libya in December 1990 with the objective of familiarizing women in developing countries with renewable energy development and technology [240].

Another approach of community college type of educating people that is popular in Sweden is called study circles. A typical study circle consists of a circle leader – the teacher – and 5–10 participants. Especially during the 1990s, knowledge about solar heating was spread in many locations in Sweden in this form, where each study group built a solar heating system at one of the participants' house, using a popular build-yourself solar collector kit [347]. A thorough investigation of this kind of education is presented in a case study [348].

Appendix-B. Solar Energy Research Center (SERC) and European Solar Engineering School (ESES) at Dalarna University, Borlange (Sweden)

Solar Energy Research Center (SERC)

The SERC pre-history dates back to the academic year 1978/9 when Lars Broman taught a 1-year half-time course on solar energy, built on Meinel and Meinel [349] plus quite a few laboratory experiments. A few years later, Broman got interested in nonimaging concentrators, which lead to a first publication on the subject [350]. The following year, the formation of a new research centre began, initially focusing on non-imaging optics [351,352]. Soon, SERC also begun work with the then dominant solar energy simulation programme TRNSYS and developed a user friendly input to it, which was named PRESIM [353–355]. This work led to contacts with the Solar Energy Laboratory at University of Wisconsin and consequently Prof. John Duffie came to Borlänge in 1990 and taught the preliminary version of the second edition of Duffie and Beckman [259], see Ref. [356].

At SERC, studies of solar thermal systems became increasingly important and new researchers joined the centre, developing an efficient low-flow system [357]. Also, studies on social aspects of solar energy have become increasingly important at SERC [348], as well as solar energy for developing countries [358,359]. Other interests of SERC has included thermophotovoltaics [360–362].

Solar energy education has since the beginning been of great interest in SERC [363] and in 1989 SERC, together with Konrad Blum at University of Oldenburg and Aadu Ott at University of Göteborg initiated International Association for Renewable Energy Education IASEE (see separate Appendix). Duffie's 1990 course was adapted into a 5-week full-time course in solar thermal energy engineering and taught several times at Dalarna University [364]. In 1999 started at SERC the 1-year Master programme named European Solar Engineering School ESES where the "Duffie course" became one of the brick stones.

More information about SERC can be found on its web page. (http://www.du.se/serc)

European Solar Engineering School (ESES)

Following a tour to Italy and the island of Capri in 1996, Lars Broman formed a project group, eventually consisting of him and Konrad Blum, Vanni Garofoli, Lars Kristoferson, Ulf Kusoffsky, and Bengt Hidemark. Their task was to create a European Solar Engineering School (ESEC) at the site of the former Swedish Solar Observatory on Capri [365]. The site had however been sold by the Swedish Royal Science Academy to the Italian Science Academy, and it turned out that their ideas about what to use the site for were not compatible with the idea of a school for young engineering students.

During the ESES preparation work, however a curriculum for a 1-year (40-week) Masters Programme in solar energy engineering was written consisting of four 5-week (7.5 cr.) courses and 20 weeks (30 cr.) of thesis work under the auspices of SERC (and Dalarna University). In the summer of 1998, a first 7.5 credit course in solar thermal engineering was given as a boarding school course at Tingvall in Bohuslän, Sweden with 12 students (of them several Ph.D. students) and Lars Broman as lecturer. This course used Duffie and Beckman [259] as text book. The next summer, another course was given at Tingvall on solar electrical engineering using the books by Martin Green [366-368] on PV with as many students and with Konrad Blum as lecturer.

In Sweden, university courses are financed by state money in proportion to number of students, their accomplishments and the course lengths. Thus, with a sufficient amount of applications, SERC could be able to arrange a yearly master programme. This inherited the name ESES from the Capri project and it has since 1999 run every year and has graduated over 200 students from countries in all continents (but Antarctic). Information about ESES is found on the ESES and ESES Alumni home pages. Student thesis titles are found at the University's DIVA pages.

Appendix-C. Postgraduate Programme on Renewable Energy (PPRE)

The PPRE started at Carl von Ossietzky University of Oldenburg, Niedersachsen, Germany in 1987. It is a 3-semester programme especially aimed for students from developing countries, who get scholarships from the German Academic Exchange Service DAAD. It has its own building, the Energilabor, with its own ground, situated at the University's science campus. The first 6 months of the programme consist of theoretical classes and laboratory courses, while the remainder is dedicated to case studies, such as development of solutions to energy supply problems arising in rural regions of developing countries [369]. Since then, some 400 students from over 80 countries have graduated from PPRE. In October 2012, the 25th anniversary was highlighted with the 2-day International Conference Renewable Energy 2030 – Experts' Visions. Detailed information about PPRE is found on their web page.

Appendix-D. Master of Technology Programmes at Centre for Energy Studies, Indian Institute of Technology Delhi (India)

The 2 year Master of Technology/programme in Energy studies was started at the Centre for Energy Studies of this institute in 1981. This programme broadly covers promising new energy sources and offers an opportunity to the students to study one of them in detail and to carry out a suitable major project in the area.

The admission to all M.Tech. programmes in the Institute is made on the basis of an all India competitive examination called GATE. Normally those who have completed M.Sc. in physics or bachelor degree in Mechanical/Electrical/Chemical engineering are eligible for admission. Seats are offered on the basis of the student's merit in GATE and his/her preference for the field of

specialization. All selected students receive scholarship and live in the student hostels of the Institute on the campus.

In July 1989, an evening M.Tech. programme in Energy Studies was started for sponsored candidate from different organizations in and around Delhi. This programme was subsequently revised to a Master of technology programme in Energy and Environmental Management in 1998.

Appendix-E. United Nations University (UNU) Sponsored Training Programme on Renewable Energy Systems at Centre for Energy Studies, Indian Institute of Technology Delhi (India)

A special training programme on Renewable Energy Systems was sponsored by the United Nations University (UNU) Tokyo (Japan) at the Centre for Energy Studies of the Indian Institute of Technology, Delhi in 1981 for active energy scientists, engineers and planners of developing countries. This training programme, one of its own kinds around the globe, was organized until the year 1998 [370,371]. However, the course curriculum and the duration of the training programme were revised from time to time in response to the feedback received from the trainees, participating faculty and the availability of resource.

General Information about the Training Programme

The training programme was designed for research and development personnel and also for those engaged in energy planning and administration. The course was also open to university teachers engaged in research and teaching to produce trained manpower in their own countries in this area. The trainees were required to have a degree in engineering or M.Sc., or equivalent of a recognized university in any related scientific discipline. They were engaged in energy planning, research or training in a government organization, sponsored by their employers and given leave for attending the training programme with salary paid during this period. There was no tuition fee for attending the training programme. All trainees received fellowship in the Indian currency and the amount of fellowship was revised from time to time. The international travel and medical insurance related expenses were also paid by the UNU.

Background of trainees

In all a total of nine batches of UNU sponsored training programme on Renewable Energy Systems at IIT Delhi since its inception in 1981. The number of countries interested in making use of the training programme in Renewable Energy Systems steadily grew over the years. In 1984, a special UNU fellow from Nigeria on Biomass for a period of 3 months and another from China on Solar Energy Utilization for a period of 6 weeks also joined the programme.

Course structure

The course work of the training programme was designed to give a strong foundation in the basic principles and their application for the development of renewable energy technologies and systems. Attention was also paid to the performance evaluation, cost effectiveness and environmental aspects of various technologies. Energy conservation techniques, energy resource assessment and planning formed an integral part of the curriculum.

Visits to industries and other centres of research exposed the trainees to various research and development programmes in the country and also provided an opportunity to see working systems in the area of renewable energy technologies. The learning experience finally culminated in a research project that put to use the knowledge acquired by the trainees to solve one of the problems relevant to their needs back home.

With the above broad outline, a three semester 12 month training programme was initiated in 1981. In 1983, on the basis of feedback received from the trainees, the course on fuel technology was replaced by a course on Biomass and in 1986 a further revision was made within the same duration of 12 months.

Owing to severe budgetary constraints it was decided to curtail the training programme, and an 8 month course structure was evolved in consultation with the UNU. Three batches (1989, 1990–91 and 1991–92) were trained following the 8 month course structure. With the feedback from these three batches and associated faculty, the course structure was modified.

Suggestions from UNU fellows

Some of the important suggestions were as following:

(a) One of the most common suggestions made by the trainees was that a diploma/degree should be awarded to the successful candidates even if it requires some changes in the course duration and curriculum. The trainees were awarded a certificate of successful completion of advanced training in the area of renewable energy systems which was not recognized as a formal diploma/degree.
(b) A number of trainees suggested that the practical design and development aspect of the course work should be increased further.
(c) Most of the participants of the 8 month training programme complained of time as the major constraint, particularly for the project work. It may be recalled that with reduction of course duration from 12 months to 8 months, while the contact hours for theory and laboratory classes were maintained at almost the same number, the time available for the project work was reduced to about 2/3 of the available time in 12 month course curriculum.
(d) There were several suggestions for addition/deletion of certain courses or their portion in the course curriculum. Such suggestions, however, depend upon the educational background and job responsibilities of the trainee. For a broad based course, it is necessary to give exposure in all related fields of renewable energy sources.
(e) Almost all trainees suggested more field trips and site visits during the training which they found very useful and educative.
(f) There were useful feedbacks from some trainees regarding the selection of candidates for a particular batch. If the group is heterogeneous in terms of their educational and professional backgrounds, it usually becomes very difficult for the course teacher to decide the speed of deliberations. It was suggested that preferably for a given batch, candidates with similar background may be selected and the course curriculum is accordingly shaped.
(g) Some trainees strongly advocated for the need of follow up programmes after the completion of the training so that they can make perceptible impression on energy policy, planning and technology development in their respective countries. This could include financial as well as advisory support at least in the initial stages. Refresher courses for the former UNU fellows have also been suggested.
(h) More use of audio-visuals, availability of lecture notes for all the classes and frequent group discussions are also suggested by the trainees.

Appendix-F. Proposed course-structure of a postgraduate-level course in energy engineering

A course structure of a postgraduate-level course in the area of energy engineering was developed under the UNESCO Chair project at the Centre for Energy Studies of Indian Institute of Technology Delhi, India [125,372]. The proposed course structure is described in the following paragraphs:

Desirable features of postgraduate teaching programme in energy engineering

Owing to the relatively involved and interdisciplinary nature of the field, the course structure of any postgraduate-level teaching programme in energy engineering should have the following characteristics to ensure its effectiveness and utility to the students and to the society:

(a) It should provide an opportunity to the students to learn and apply the basics of new subjects relevant to the area of energy engineering.
(b) The course curriculum should ensure that on successful completion of the programme the students have a solid background of extensive and comprehensive course-work in all essential advanced-level subjects.
(c) The students should be able to specialize in any one (or more, if additional courses are taken) of the coherent and consistent aspects of energy engineering and acquire in-depth knowledge and necessary skills in that area rather than having just surface-level knowledge of many diversified subjects.
(d) The course structure of the teaching programme should cover all aspects of the energy technologies, including resource assessment, technology development, economics and energetic, socio-cultural issues, and ecological and environmental impacts, etc.
(e) It should be flexible and dynamic, thus allowing for future improvement in course-structure.
(f) It should provide a balance between theory and practical aspects of energy engineering education.
(g) It should be compatible with global efforts in this direction to allow effective and mutually beneficial experience sharing and interaction with other countries.

Objectives

In an attempt to accommodate most of the desirable features mentioned in the foregoing section the course-structure of the proposed postgraduate teaching programme in energy engineering is framed with the following objectives: (a) to provide an opportunity to the students of diverse educational and professional backgrounds to acquire basic knowledge in certain new subjects directly relevant to the interdisciplinary area of energy engineering, (b) to enable the students acquire a strong foundation in all the advanced-level important areas such as energy conversion, heat and mass transfer, fluid mechanics, combustion, instrumentation and control, energy conservation, etc. and (c) to offer the students an opportunity to specialize in one of the three options – conventional energy engineering, energy management and planning, and renewable energy engineering. On successful completion of the teaching programme the students should be able to design, evaluate and select appropriate energy technologies to meet a given energy demand.

Course-structure

The salient features of the proposed course structure are summarized in Table F1. A listing of various courses and corresponding contact hours is presented in Table F2.

In view of the possibility of a group with heterogeneous academic background opting for the three-semester postgraduate programme in Energy Engineering, a set of bridge courses is offered in the beginning. Each bridge course is to be covered in 20 contact hours. Every student is required to take a minimum of four bridge courses, depending upon his educational background. Each student has to study 13 compulsory (core) courses with 20 contact hours each. These include a compulsory course on advanced engineering laboratory. Three options for specialization are then offered to the student. Depending upon the area of specialization the student needs to opt for a minimum of eight elective courses, including a compulsory course of energy laboratory to fulfil the pre-specified credit requirement.

Appendix-G. International association for solar energy education (IASEE)

Three solar scientists interested in solar energy education (Konrad Blum, Lars Broman and Aadu Ott) met during the International Conference North Sun'88 and begun to discuss the importance of forming an international association for solar energy education. After about 1 1/2 years, they again met in Göteborg in November 1989 and founded IASEE [373]. The board

Table F1
Proposed postgraduate-level teaching programme in the area of energy engineering.

1.	Eligibility	Bachelor degree in engineering or Master degree in physical sciences
2.	Time duration	Three semesters (for full-time students) or Five semesters (for part-time students)
3.	Degree awarded	Postgraduate degree in energy engineering or Postgraduate diploma in energy engineering
4.	Components of the course	It consist of (a) Theory courses (b) Laboratory courses (c) Research project to be undertaken by the student
5.	Hours of contact	A total of 610 h of contact (besides the research project) which include 240 h of compulsory theory courses and 80 h of compulsory laboratory course-work. For each additional specialization option the student will have to undergo 210 h of theory and 60 h of laboratory course-work.
6.	Course distribution (for full-time students)	I Semester: (a) Bridge courses (b) Core courses II Semester: (a) Core courses (b) Courses of specialization option (c) Research project III Semester: (a) Courses of specialization option (b) Research project
7.	Language	To begin with it is proposed to offer the teaching programme in English only. Once established, similar programme in other languages (e.g. French, Spanish, etc.) may also be offered.

Table F2
Topic-wise contact hours for bridge, core and specialization courses.

S. No.	Course	Contact hours
(A) Bridge courses		
1.	Thermodynamics	20
2.	Heat and Mass Transfer	20
3.	Fluid Mechanics	20
4.	Applied Physics	20
5.	Engineering Mathematics	20
6.	Natural Resource Economics	20
7.	Principle of Electrical Engineering	20
8.	Principle of Chemical Engineering	20
9.	Engineering Laboratory	20
(B) Core courses		
1.	Energy Resources	20
2.	Advanced Heat and Mass Transfer	20
3.	Advanced Thermodynamics	20
4.	Advanced Fluid Mechanics	20
5.	Combustion Engineering	20
6.	Energy Systems Technology	20
7.	Economics of Energy Technology and Systems	20
8.	Basics of Energy Conservation	20
9.	Energy, Ecology and Environment	20
10.	Instrumentation and Control in Energy Systems	20
11.	Energy Storage	20
12.	Advanced Energy Systems	20
13.	Advanced Engineering Laboratory	20
(C) Specialization courses		
Conventional Energy		
1.	Energy Engineering Equipment -I	30
2.	Energy Engineering Equipment –II	30
3.	Coal Technology	30
4.	Petroleum Technology	30
5.	Gas Technology	30
6.	Nuclear Technology	30
7.	Hydroelectric Power	30
8.	Energy Aspects of Environmental Control	30
9.	Power Systems Engineering	30
10.	Energy Laboratory-I (compulsory)	60
Energy Management and Planning		
1.	Energy Auditing	30
2.	Energy Analysis	30
3.	Industrial Energy Conservation	30
4.	Rural Energy Conservation	30
5.	Energy Management in Buildings	30
6.	Energy from Wastes	30
7.	Energy Planning-I	30
8.	Energy Planning-II	30
9.	New and Renewable Sources of Energy	30
10.	Energy Laboratory-II (compulsory)	60
Renewable Energy Engineering		
1.	Solar Energy Thermal Utilization	30
2.	Biomass Energy	30
3.	Wind and Microhydel	30
4.	Passive Solar Building	30
5.	Direct Energy Conservation	30
6.	PV Systems Engineering	30
7.	Commercial and Industrial Utilization of Renewable Energy	30
8.	OTEC, Wave, Tidal and Geothermal Energy	30
9.	Integrated Energy Systems	30
10.	Energy Laboratory-III (compulsory)	30

of the International Solar Energy Society ISES met during the First World Renewable Energy Congress in Reading, UK in 1990 and decided that IASEE should be ISES Working Group for Education [374–376].

IASEE grew to consist of over 400 members from 80 countries in 5 continents, both developed and developing countries. The IASEE activities included

– membership meetings odd years during ISES World Congresses and even years during WREC Congresses,
– publication of Progress in Renewable Energy Education PREE, 5 issues which were published during 10 years, and
– arranging International Symposiums of Renewable Energy Education: ISREE-1 and -3 1991 and 1993 in Borlänge, Sweden; ISREE-2 and -5 1992 and 1996 in Oldenburg, Germany; ISREE-4 1994 in Bangkok, Thailand; ISREE-6 1998 in New Delhi, India; ISREE-7 2000 in Oslo, Norway; ISREE-8 and -11 2002 and 2005 in Orlando, Florida, USA; ISREE-9 during ISES'03 in Göteborg, Sweden; ISREE-10 in Perth, Australia;

Presently (2012–2013), IASEE seems to have no activities.

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